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(54) FUEL FEED CONTROL DEVICE FOR INTERNAL COMBUSTION ENGINE

(71) We, HITACHI, LTD., a Corporation organised under the laws of Japan, of 5-1, 1-chome, Marunouchi, Chiyoda-ku, Tokyo, Japan, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed to be particularly described in and by the following statement:—

This invention relates to a fuel feed control device for an internal combustion engine, particularly to an improvement in the responsiveness of an electromagnetic valve utilized as means for controlling fuel feed quantity in a fuel feed control device. The fuel feed control device can control the fuel feed quantity with high accuracy.

Two different types of control valves are known for use in a fuel feed control device for an internal combustion engine, in which a fuel injection nozzle is disposed to be opened into a suction pipe of the internal combustion engine so that the engine is fed with desired fuel quantity by controlling the opening duration of the control valve. One of the two types of control valves is driven mechanically and another electromagnetically.

In recent years, a fuel feed control device using the latter type of the controlled valve, namely an electromagnetic valve, has become more advantageous than the former because of the ease in detecting various control factors, the ease in determining the quantity to be controlled, and the improvement in the control elements including semiconductive parts and the like.

The most serious trouble which reduces the accuracy of the control operation in a fuel feed control device using an electromagnetic valve is the slowness of response in the opening and closing operation of the electromagnetic valve. Other difficulties arise due to various errors, for example errors in detecting process of various control factors, errors in computing process, and deviation of fuel feed pressure and the like.

The opening duration of a fuel injection valve, which is used in an internal combustion engine as a fuel feed means, is determined so that a suitable quantity of fuel is fed into the engine according to the engine speed and the load.

However, since the speed of an internal combustion engine varies over a wide range from about 600 r.p.m. to 6000 r.p.m., any error in the fuel quantity fed to the engine leads to a reduction of the operation efficiency of the engine. This is undesirable particularly in view of the increasing quantities of harmful exhaust gas emitted. In practice, however a time lag occurs in the process of the opening and closing operation of an electromagnetic valve used as a fuel injection valve, when the engine is running at high speed, with the result that the fuel feed quantity tends to be inaccurate.

A fuel feed device according to the present invention comprises a fuel feed control device for an internal combustion engine comprising an electromagnetically operated, normally closed fuel injection valve, the valve electromagnet having at least two coils or windings and control means so arranged that at least one of the coils is capable of producing magnetic flux in such a direction as to close the valve, and at least one other, or the other coil is capable of producing a magnetic flux which is only sufficient to hold the valve open once it has been opened (hereinafter referred to as a "holding flux"), the control means being so arranged and so connected to the said coils that when the valve is to be opened, a holding current can first be passed through the said one other or the other coil to produce a holding flux, then an opening current can be passed through one of the coils to produce a flux sufficient to open the valve, and when the valve is to be closed, a current can be passed through the said one coil which is such as to close the valve.

The device of the present invention may

thus provide an arrangement in which the responsiveness in opening and closing operation of the valve is improved to thereby improve the accuracy of the fuel feed control and enable the control device to be applicable to a high speed engine.

Some embodiments of the invention will now be described by way of example with reference to the accompanying drawings, in which:

Fig. 1 shows a conventional electric circuit for driving an electromagnetic valve;

Fig. 2 shows fuel feed quantity characteristic curves;

Fig. 3 is an explanatory drawing illustrating the operation state of the respective electric circuits shown in Figs. 5, 6 and 7;

Fig. 4 shows a characteristic curve illustrating the function of the embodied device of the present invention in the process of the valve closing operation;

Figs. 5, 6 and 7 show electric circuits of various embodiments of this invention;

Fig. 8 shows an electric circuit of a further embodiment of this invention;

Fig. 9 is an explanatory drawing illustrating the operation state of the electric circuit shown in Fig. 8;

Fig. 10 is a sectional view showing the structure of an electromagnetic valve of an embodiment of this invention; and

Fig. 11 is a plan view of the electromagnetic valve shown in Fig. 10.

Referring to Fig. 1, a series circuit consisting of electromagnetic coil 2, a resistor 3, and the collector-emitter circuit of a transistor 5 is connected between an electric power supply terminal 1 and an earth, and the base electrode of the transistor 5 is connected to a control signal input terminal 7 through a resistor 6, while a capacitor 4 is connected in parallel with the resistor 3.

In the above circuit, the inner resistance between the collector and emitter electrodes of the transistor 5 is controlled by supplying a bias voltage to the base electrode of the transistor 5 from the control signal input terminal 7, so that the opening and closing operation of an electromagnetic valve for controlling the fuel feed quantity can be controlled.

Because the capacitor 4 is connected in parallel with the current limiting resistor 3, the electromagnetic coil 2 is energized to open the electromagnetic valve by a large current passing through the coil 2 and the capacitor 4 for a transient duration when the valve is rendered open, and, after the charging of the capacitor 4 has been completed, the coil 2 is energized by a current which is large enough to hold the open state of the valve and called a holding current hereinafter.

When the voltage causing the flow of holding current is removed from the coil 2 to render the valve closed, the valve is not completely closed immediately. This is because a counter-electromotive force proportional to the rate of decrease of the holding current and opposing the decrease is induced in the electromagnetic coil the instant the said voltage is removed from the coil and, at the same time, an eddy current is also induced in the magnetic material constituting a magnetic circuit for the electromagnetic valve in a manner so that the magnetic flux which has been induced by the holding current is prevented from disappearing. These counter electromotive force and eddy current are gradually reduced with time with the result that the magnetic attraction force of the valve which has been prevented by those counter electromotive force and eddy current from disappearing also gradually reduces with time.

As a result, the valve is kept in the fully open state until the electromagnetic attraction force is reduced to be equal to the force for closing the valve which is usually given by a spring means or the like, and then the degree of the prevention of the closing operation of the valve is gradually reduced so as to completely close the electromagnetic valve.

The time required for the closing operation of the valve changes in connection with the magnitude of the force of the spring for closing the valve and the inertia of the movable portion of the valve, etc.

The known device shown in Fig. 1 attempts to improve the responsiveness in the valve opening operation by passing a sufficiently large current through the electromagnetic coil when the valve is rendered open from the closed state thereof, as well as the responsiveness in the valve closing operation by reducing the production of the above-mentioned counter electromotive force and eddy current as much as possible when the valve is rendered closed from the open state thereof. The above-mentioned counter electromotive force and eddy current can be somewhat reduced by holding the valve with a reduced holding current in its open state.

Fig. 2 shows the characteristic curves illustrating the relationship between the fuel feed quantity per one injection and the demanded time for opening the electromagnetic valve, in which the curve A represents an ideal state of the device having no time lag in response in the process of the opening and closing operation of the valve and the curve B a practical state having a time lag.

If the fuel feed control device had an

ideal characteristic as shown by the curve A, the electromagnetic valve could be immediately fully opened in response to a demand signal for opening the valve and immediately closed when the demand signal was removed even if the demanded time was very short. As a result, the relationship between the demanded time and the fuel feed quantity per one fuel injection would vary linearly.

On the other hand, in practice as shown by the curve B, the electromagnetic valve cannot be opened at all if the demanded time for opening the valve is very short. Even if the demanded time is increased a little, the demand signal may be removed so that the electromagnetic valve closes before it becomes fully open. Accordingly, the relationship between the fuel feed quantity per one injection and the demanded time varies non-linearly. The electromagnetic valve may be fully opened if demanded time is further increased. On the other hand, in this event, the valve may be kept in its open state when the demand signal is removed if the response of the valve closing operation is rather slow, resulting in an increase of the fuel feed quantity greater than in the case where the response rate is high in response to the same demanded time for opening the valve.

In an ideal fuel feed control device using an electromagnetic valve having a characteristic as shown by the curve A in Fig. 2, it is relatively easy to control a desired fuel feed quantity between the necessary minimum value Q1 and the necessary maximum value Q2 in the period for controlling the fuel feed quantity between the minimum value T1 and the maximum value T2 because of the linear relationship between the demanded time and the fuel feed quantity per one fuel injection. Further, it is possible to make the maximum value Q2 large, while the maximum value T2 remains as it is, or to make the maximum value T2 small, while the maximum value Q2 remains as it is, or to make the maximum values Q2 and T2 large and small respectively, at the same time, by increasing the fuel feed pressure or enlarging the mechanical dimension of the fuel measuring member of the device, etc.

On the other hand in a fuel feed control device comprising an electromagnetic valve having a characteristic as shown by the curve B in Fig. 2, the demanded time required for opening the valve corresponding to the necessary minimum value Ql exists in a non-linear portion of the characteristic curve B, resulting in the complication of the control device and the reduction of the accuracy in the control operation. It is possible, of course, to make the maximum value Q2 large, while the maximum value T2 remains as it is, or to make the maximum value T2 small, while the maximum value Q2 remains as it as, or to make the maximum values Q2 and T2 large and small respectively at the same time, in the same manner as above, namely by increasing the fuel feed pressure or enlarging the mechanical dimension of the fuel measuring member of the device, etc. However, even if the above requirement can be thus satisfied by increasing the fuel feed quantity per unit time near the maximum value Q2, the non-linear portion near the minimum value Ql is enlarged with the result that the accuracy in the control operation may be greatly reduced or, sometimes, it may become impossible to perform the control operation.

To resolve the above problem, it is required to improve the responsiveness in valve closing operation, which is to be regarded as just as important as improving the responsiveness of the valve opening operation.

Fig. 5 shows an electric circuit of one embodiment of the invention, in which an electromagnetic coil 12A for holding the open state of an electromagnetic valve, a holding current limiting resistor 3 and a holding current control transistor 15E are connected in series between an electric power supply terminal 1 and earth. Further, a series circuit consisting of a valve opening control auxiliary transistor 15B, an electromagnetic coil 12B for opening the electromagnetic valve and a valve opening control transistor 15A is also connected between the terminal 1 and earth. Transistors 15C and 15D are connected in parallel relation with the series portion consisting of the electromagnetic coil 12B and the transistor 15B and the series portion consisting of the electromagnetic coil 12B and the transistor 15A, respectively. The base electrodes of the transistors 15A, 15B, 15C, 15D and 15E are connected to control signal input terminals 17A, 17B, 17C, 17D and 17E through resistors 16A, 16B, 16C, 16D and 16E respectively.

The holding current control transistor 15E, the valve opening control transistor 15A and the valve opening control auxiliary transistor 15B are respectively controlled to function in agreement with the patterns shown in Fig. 3a, Fig. 3b and Fig. 3c. The circuit is arranged in the manner so that the electromagnetic attraction force due to the current flowing through the electromagnetic coil 12B additionally co-operates with the electromagnetic attraction force due to the holding current which flows through the electromagnetic coil 12A. Further, the backward current control auxiliary transistor 15C and the backward current control transistor 15D are

both controlled to function in agreement with the pattern shown in Fig. 3c. The sequence of operation of the circuit is illustrated in Fig. 3 and is as follows:

At first only the holding current control transistor 15E is conductive so that a current flows from the electrical power supply terminal 1 to earth through the electromagnetic coil 12A, the holding current limiting resistor 3 and the holding current control transistor 15E. This current produces an electromagnetic force which cannot render the valve open from its closed state but can hold it in its open state once the valve is opened.

Then, the valve opening control transistor 15A and valve opening control auxiliary transistor 15B are rendered conductive so that a large forward current flows through the path of the forward current control auxiliary transistor 15B, the electromagnetic coil 12B and the valve opening control transistor 15A. The holding current control transistor 15E remains conductive. The valve opening transistor 15A and auxiliary transistor 15B are controlled to be kept conductive for a desired time and then rendered non-conductive again.

When the electromagnetic valve is to be rendered closed from its open state, the holding current control transistor 15E is rendered non-conductive, while, at the same time, the backward current control auxiliary transistor 15C and the backward current control transistor 15D are rendered conductive and kept in the conductive state for a desired time. As a result, a current flows backwards from the electric power supply terminal 1 to earth through the backward current control auxiliary transistor 15C, the backward current control transistor 15D and the electromagnetic coil 12B. Fig. 3d shows the wave form of the current flowing through the electromagnetic coil 12B. In the wave form, the transient characteristic of the current due to the inductance of the electromagnetic coil and the like is neglected. Fig. 3e shows the opening and closing state of the electromagnetic valve, in which the responsiveness of the valve is also neglected.

In the circuit shown in Fig. 6, a series circuit consisting of a valve opening control electromagnetic coil 22A and a valve opening control transistor 25A and another series circuit consisting of a backward flux control electromagnetic coil 22B and a backward flux control transistor 25B are connected in parallel relation between an electric power supply terminal 1 and earth. A series circuit consisting of a holding current limiting resistor 3 and a holding current control transistor 25C is further connected in parallel with the collector-emitter circuit of the transistor 25A. The base electrodes of the transistors 25A, 25B and 25C are connected to control signal input terminals 27A, 27B and 27C through resistors 26A, 26B and 26C respectively.

The holding current control transistor 25C, the valve opening control transistor 25A and the backward flux control transistor 25B are respectively controlled to function in agreement with the patterns shown in Figs. 3a, 3b and 3c. The coils are arranged in the device so that the magnetic flux produced by a current flowing in the electromagnetic coil 22B during the conduction of the transistor 25B cancels the magnetic flux which is induced by the electromagnetic coil 22A during the conduction of the transistor 25A, whereby the same effect on the control operation can be obtained as in the circuit of Fig. 5.

In the circuit of Fig. 7 a series circuit consisting of a holding electromagnetic coil 32A, a holding current limiting resistor 3 and a holding current control transistor 35A, another series circuit consisting of a valve opening electromagnetic coil 32B and a valve opening control transistor 35B and still another series circuit consisting of a backward flux control electromagnetic coil 32C and a backward flux control transistor 35C are connected in parallel relation between an electric power supply terminal 1 and earth, while the base electrodes of the transistors 35A, 35B and 35C are respectively connected control signal input terminals 37A, 37B and 37C through resistors 36A, 36B and 36C. If the electric and magnetic characteristics of the coil 32A are suitably selected, the holding current limiting resistor 3 may be eliminated.

The holding current control transistor 35A, the valve opening control transistor 35B and the backward flux control transistor 35C are respectively controlled to function in agreement with the patterns shown in Figs. 3a, 3b and 3c. The coils are arranged so that the respective magnetic fluxes produced by the currents flowing through the electromagnetic coils 32A and 32B additionally cooperate with each other and the magnetic flux produced by the current flowing through the electromagnetic coil 32C cancels both the former magnetic fluxes, whereby the same effect on the control operation is obtainable as stated in connection with the embodied circuit of Fig. 5.

Fig. 8, shows an electric circuit of an improved high speed type of fuel feed control device of another embodiment of this invention.

In the circuit of Fig. 8, a series circuit consisting of transistors 45B and 45D and another series circuit consisting of 45C and

45A are connected in parallel between an electric power supply terminal 1 and earth, a valve opening-closing control electromagnetic coil 42A is connected between the junction point of the two collector electrodes of the transistors 45A and 45C and the junction point of the two collector electrodes of the transistors 45B and 45D, and a series circuit consisting of a resistor 3 and a holding current control coil 42B is connected in parallel with the emitter-collector circuit of the transistor 45B. Further, the coils are arranged in a manner so that the magnetomotive force due to the current flowing from the terminal 1 to earth through the resistor 3, the holding current control coil 42B and the transistor 45D and the magnetomotive force due to the current flowing from the terminal 1 to earth through the transistor 45C, the valve opening-closing control coil 42A and the transistor 45D co-operate additionally with each other.

In the thus arranged circuit, when the transistors 45A, 45B, 45C and 45D are controlled, respectively, so as to function in agreement with the patterns of Fig. 9c, Fig. 9c, Fig. 9b and Fig. 9a by supplying the respective base electrodes of the transistors with required control signals through resistors 46A, 46B, 46C and 46D from control signal input terminals 47A, 47B, 47C and 47D, the circuit functions to produce a magnetomotive force in agreement with the pattern shown in Fig. 9d neglecting the transient state thereof. Therefore, the same effect on the control operation is obtainable as shown in Fig. 3d and the electromagnetic valve is controlled to operate in agreement with the pattern shown in Fig. 9e.

This circuit according to the invention has the advantage in that a large current is not required to pass through the holding current control coil 42B, so that the number of turns in the coil can be much increased by using a fine conductive wire.

Further, if the coil material or the number of turns in the coil is suitably selected, the resistor 3 may be eliminated.

Furthermore, in this control device, the holding current control coil 42B requires no special control element in the circuit.

Fig. 4 is a diagram of the operation of the control devices according to the present invention (curve B) compared to the prior art (curve A) and it will be seen that in the valve closing operation, the movable member of the valve collides with the fixed member thereof in an elastic manner and rebounds repeatedly several times. The magnitude and the number of the rebounds can be reduced to some degree by suitably selecting the magnitude and duration of the backward current.

Referring to Fig. 10, the fuel is led into the opening of the opening of a core 121 through a suitable connection pipe and, then, it is further led through the respective hollow portions of an adjuster 124, and a needle 133 and the side hole of the needle 133 to a seat portion composed of a nozzle 134 and the needle 133. Besides this, the fuel may reach the seat portion through the outer periphery of the needle 133. An actuator 131 is attracted upward in the drawing by an electromagnetic force, so that the seat is open to feed the fuel.

The magnetic circuit of this device is composed of the core 121, a yoke 128, the needle 133 and the actuator 131. One electromagnetic coil 127A for holding the open state of the valve is wound on the inside or outside of a coil bobbin 126 and then insulated with an insulating material. After insulating the coil 127A, another electromagnetic coil 127B for controlling the opening-closing operation of the valve is wound outside or inside of the insulator 129. Accordingly, each of the coils 127A and 127B can produce a magnetic field independently.

The number of turns of the holding coil 127A can be increased to decrease the required current flowing therethrough and the rising characteristic in the transient period of the current flowing through the valve opening-closing control coil 127B can be improved by utilizing relatively thick wire as a winding material and decreasing the number of turns thereof. Depending on the construction of the external control circuit, one terminal of each of the respective coils 127A and 127B may be connected together, so that the four terminals of the two coils are reduced to three terminals 123A, 123B and 123C as shown in Fig. 11 to thereby enable the wiring in the device to be simplified.

The fuel injection valve used in conjunction with the circuits of the present invention is preferably provided with an improved mechanism for adjusting the responsiveness of the injection valve. The adjustment of the responsiveness of the valve has previously been performed by adjusting the reaction force of a spring (e.g. spring 130 in Fig. 10) in an injection valve of this kind. A method has been proposed for adjusting the reaction force of the spring, in which an adjuster for pushing the spring is screwed into a core, then suitably adjusted after the injection valve is assembled, and the outer periphery of the core is caulked from the outside thereof.

However, this method has a disadvantage in that the adjusted state may be disturbed by absorbing a play of the screw portion or the like when the caulking force is applied, because there is a limit to the accuracy of a screw thread in general.

Referring to Figure 10, the outer periphery of the adjuster 124 and the inner periphery of the core 121 are precisely finished so that the adjuster 124 is slidable smoothly in the core 121. The fine finish can be easily achieved because of the circular section of the core and the adjuster. When the injection valve is assembled, the adjuster is properly adjusted by a suitable additional adjusting means before a filter 122 is added into the core 121 and then the adjusted state is fixed by applying a caulking force from the outside of the core 121. Thus, the problem of the disturbance in adjustment due to the inaccuracy of a screw thread can be solved.

WHAT WE CLAIM IS:—

1. A fuel feed control device for an internal combustion engine comprising an electromagnetically operated, normally closed fuel injection valve, the valve electromagnet having at least two coils or windings and control means so arranged that at least one of the coils is capable of producing magnetic flux in such a direction as to close the valve, and at least one other, or the other coil is capable of producing a magnetic flux which is only sufficient to hold the valve open once it has been opened (hereinafter referred to as a "holding flux"), the control means being so arranged and so connected to the said coils that when the valve is to be opened, a holding current can first be passed through the said one other or the other coil to produce a holding flux, then an opening current can be passed through one of the coils to produce a flux sufficient to open the valve, and when the valve is to be closed, a current can be passed through the said one coil which is such as to close the valve.

2. A fuel feed control device as claimed in Claim 1, in which the control means comprise transistors.

3. A fuel feed device as claimed in Claim 1 or Claim 2 in which there are two coils and the control means are so arranged that in use one coil alternatively produces both the opening and closing fluxes and the other coil produces only the holding flux.

4. A fuel feed device as claimed in Claim 3 in which the said other coil is connected in series with a switching transistor and a current limiting resistor between the poles of a power supply and one end of the said one coil is alternatively connectible via one of two switching transistors, to either of the poles of the power supply the other end of the coil being similarly alternatively connectible via one of two further transistors to either of the poles of the power supply, so that current can be supplied to the said one coil in either direction.

5. A fuel feed device as claimed in Claim 1 or Claim 2 in which there are two coils and the control means are so arranged that in use one coil produces only the closing flux and the other coil produces both the opening and holding fluxes.

6. A fuel feed device as claimed in Claim 5 in which the said one coil is connected to the power supply via a switching transistor and the said other coil is connected to the power supply via a pair of switching transistors connected in parallel, one of the pair of transistors having a current limiting resistor connected in series therewith.

7. A fuel feed device as claimed in Claim 1 or Claim 2 in which there are three coils or windings, the control means being so arranged that in use one coil produces the closing current, a second coil produces the opening current, and a third coil produces the holding current.

8. A fuel feed device as claimed in Claim 7 in which each coil is separately connected to the power supply via a respective switching transistor, the "holding" coil also having a current limiting resistor connected in series therewith.

9. A fuel feed control device substantially as herein described with reference to any one of Figs. 5, 6, 7 and 8 of the accompanying drawings.

LANGNER PARRY
Chartered Patent Agents
59—62 High Holborn,
London, WC1V 6EJ
Agents for the Applicants

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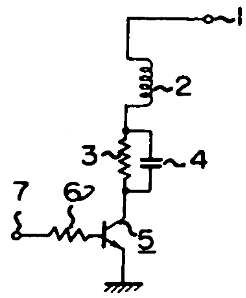
FIG.1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3
4
7
6
5

FIG.2

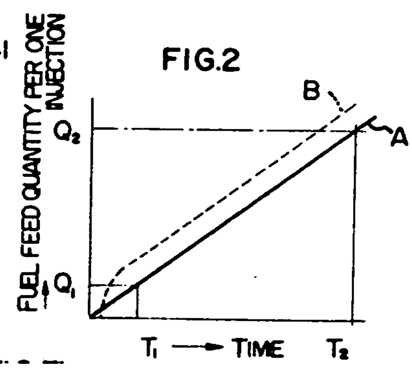
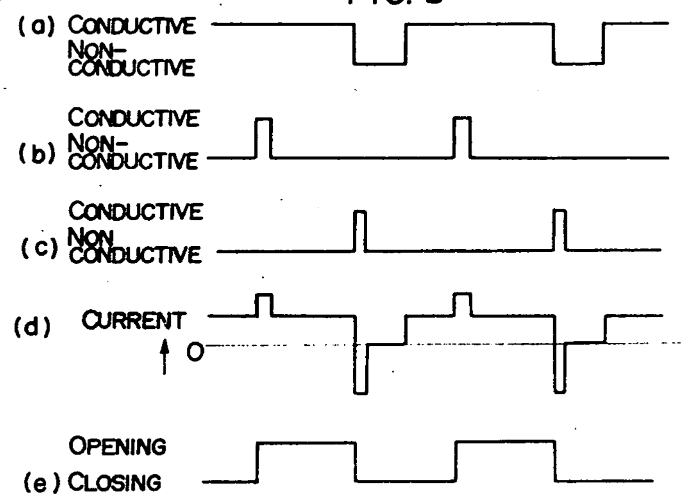

FUEL FEED QUANTITY PER ONE INJECTION
B
A
Q2
Q1
T1
TIME
T2

FIG. 3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(b) CONDUCTIVE
NON-CONDUCTIVE
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NON CONDUCTIVE
(d) CURRENT
0
(e) OPENING
CLOSING

FIG. 4

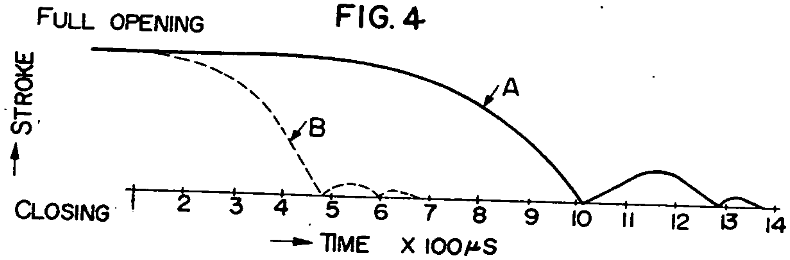


FIG. 5

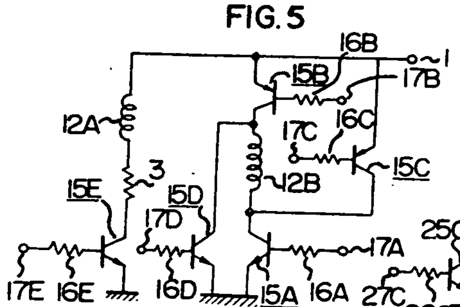


FIG. 6

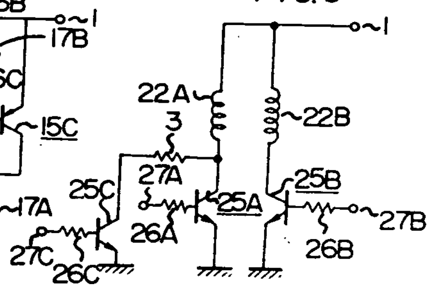


FIG. 7

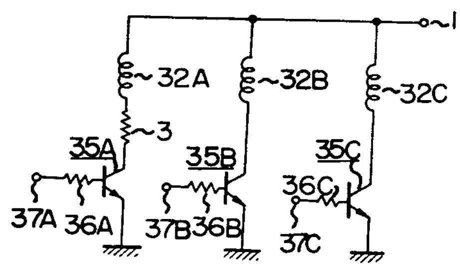


FIG. 8

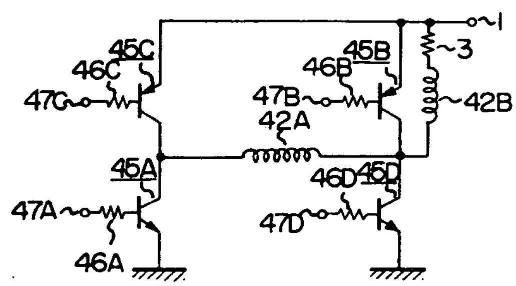
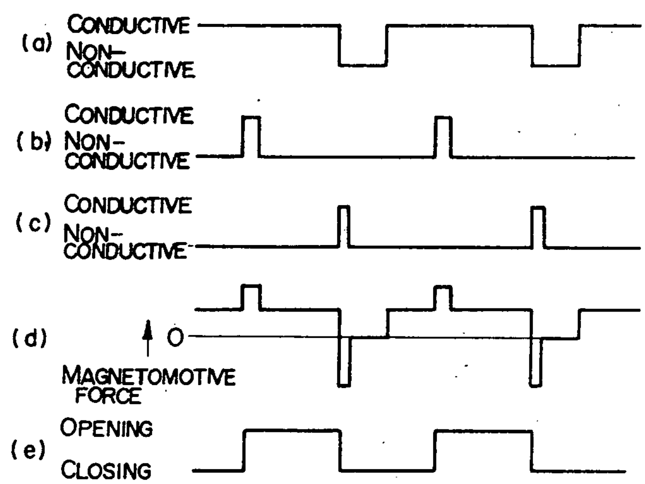

45C
46C
47C
45B
46B
47B
~3
~42B
42A
45A
47A
46A
46D
45D
47D
~1

FIG. 9

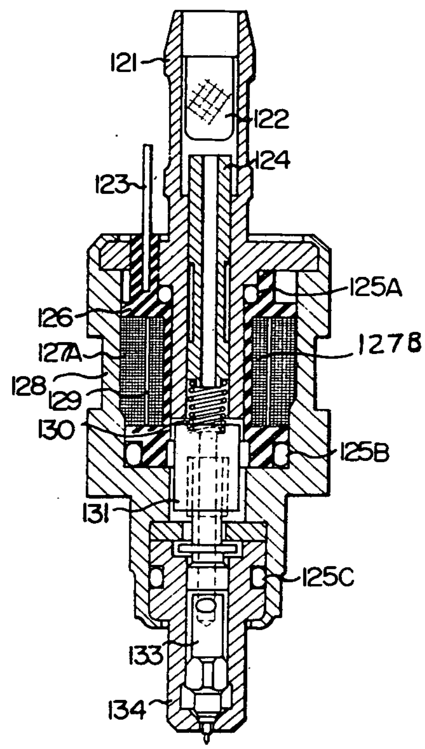

(a)
CONDUCTIVE
NON-CONDUCTIVE
(b)
CONDUCTIVE
NON-CONDUCTIVE
(c)
CONDUCTIVE
NON-CONDUCTIVE
(d)
0
MAGNETOMOTIVE FORCE
(e)
OPENING
CLOSING

1427995 COMPLETE SPECIFICATION

6 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 5

FIG.10



1427995 COMPLETE SPECIFICATION

6 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 6

FIG. 11